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Evaluating the Performance of Multi-Input Converter Topology with Different Sources of Energy

[1]Payal Deshpande, [2]Pragya Nema

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Abstract

The proposed Multi input DC-DC converter topologies are introduced for two input energy sources. The converters have the capability to simultaneously deliver power to the load, from the input energy sources. The major advantages of the improved converter as compared to the basic topology are its capability to perform the buck, boost and buck-boost modes of operation using the same structure and the ability to deliver power to the load, even with the failure of any one of the input energy sources. Hence the detailed software simulation of the improved converter has been performed using MATLAB/Simulink platform. The state topology is individually presented from the buck; boost and buck boost operation of converter which indicates the integration of two renewable energy sources. The proposed converters have certain merits like less component count, compact structure and efficient energy utilization, compared to existing converter topologies which are already reported in the literature.

Key Word- Multi Input Converter (MIC); multiple sources; Buck Boost operation; DC-DC converter.

[1]PhD Scholar, Department of Electrical Engineering, Oriental University Indore (M.P.)

[2] Professor, Department of Electrical Engineering, Oriental University Indore (M.P.)

Corresponding author mail- nenepayal14@gmail.com

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1. Introduction

There has been a growing differential between the world energy needs and the amount of energy tapped into through various technologies. Today, Distributed Energy Resources (DER) has become quite promising in terms of meeting the world's energy needs of the future as against Centralized Energy Resources (CER) of the past. More specifically the CER were the crude oil, natural gas and other forms of non-renewable sources of energy which are contributing aggressively to the climatic change and environmental adversities [1]. Furthermore, the high cost of installing transmission lines and larger security concerns have made CER technologies uneconomical in especially the developing countries where there are pockets where grid is currently unavailable [2]. Additionally, there has been technological advancement in terms of smaller generators, power electronics and storage systems which is paving the way for further development of DER. An added advantage of such development of DER is that the intended load is closer to the generation and hence transmission line loss is saved. It must also be appreciated that no CER energy resource presently exists that meets all the economic, social, and environmental requirements. Rather the renewable forms of energy are environmental friendly, are ubiquitous, are used as a source of income and industrial development [3]. Consequently, there has been greater emphasis than ever on development of renewable sources of energy. And many governments globally are incentivizing use of renewable energy to cater to the energy gap, to stabilize the current grid, to create micro-grids where the grids are unavailable etc. This has led to a global-scale encouragement to development of DER.

2. Proposed System:

The future of energy technology is greatly dependent on the evolution of improved techniques for hybridization of two or more different energy sources. In the earlier versions of hybridization, different categories of sources were combined through separate dc-dc converters and their outputs connected in series or parallel [4]. Such arrangements of multiple input converter (MIC) topologies had limitations the remnants of which are of selection of voltage levels, limitation in the operating modes, switching scheme complexity, improper selection of switches, and inadequacy in analysis and component counts. Consequently, there has been an important role played by power electronics for better utilization of power through power conditioning. Quite apart from the reminisces of issues with MIC topologies, the inverters are required to maintain the voltage and frequency essentially constant at the consumer's terminal to ensure the system stability and satisfactory transient performance. There is various control methodologies reported in different literatures regarding the inverter control, operating in stand-alone mode [5]. The repetitive control technique suffers from its incapability to deal with the disturbances which are periodic in nature, besides that it also claims large memory for its functionality [6, 7]. The robust control (H-infinity control) technique, although capable of providing a good balance between system performance and stability margin, the two desirable but incompatible features of the system, suffers the difficulty of not being implemented on digital processors also they possess complexity in their design specifications [8, 9]. Present work takes care of all the above-mentioned frailties in incremental stage first by implementing the solution through a MIC in which the energy storing units Battery and then connected to the PV source.

A bidirectional conducting and bidirectional blocking (BCBB) switch is used in designing the MIC, instead of bidirectional conducting and unidirectional blocking (BCUB) switch. The above-mentioned changes take care of defective operating state related to undesired conduction of the BCUB switches under the event of reverse bias being applied across them [10,11]. The developed MIC is utilized to integrate a solar PV source with a storage battery source [12]. The converter has the ability for power transfer from the sources discreetly or concurrently by connecting the sources in any mode: series or parallel [13, 14] .The converter also offers the effective control of flow of power between the sources and the load. Furthermore, the proposed converter is proficient in power flow in directions and buck, boost, buck-boost operation modes. Compact design, versatility in control of power and selection of voltage source with least part count are still the other features of the proposed converter. Fig. 1 shows the equivalent switch configuration of proposed MIC.

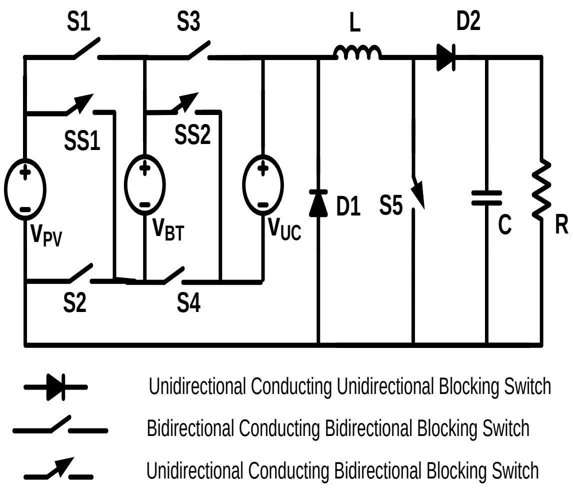

Fig. 1 Equivalent Switch configuration of proposed MIC

3. Working States

In this section, the detailed description of proposed MIC is illustrated. The proposed converter shown in fig.1 comprises of three voltage sources, (i) VPV obtained from the solar PV system, (ii) VBT obtained from the storage battery and (i) VUC obtained from UC. The switch network that combines the sources, comprises of bidirectional switches (S1-S4), unidirectional switches (SS1, SS2, S5) and diodes (D1, D2). Switch group (S1-S4) is for the parallel operation of the sources. Switch group (SS1-SS2) is for series connection of the sources. Diode, D1 is for freewheeling action. The conduction of switch S5 and diode D2 decide the converter operation in buck mode, boost mode, buck-boost mode and bidirectional mode. For converter operation in bidirectional mode, the Diodes are needed to be replaced by unidirectional controlled switches.

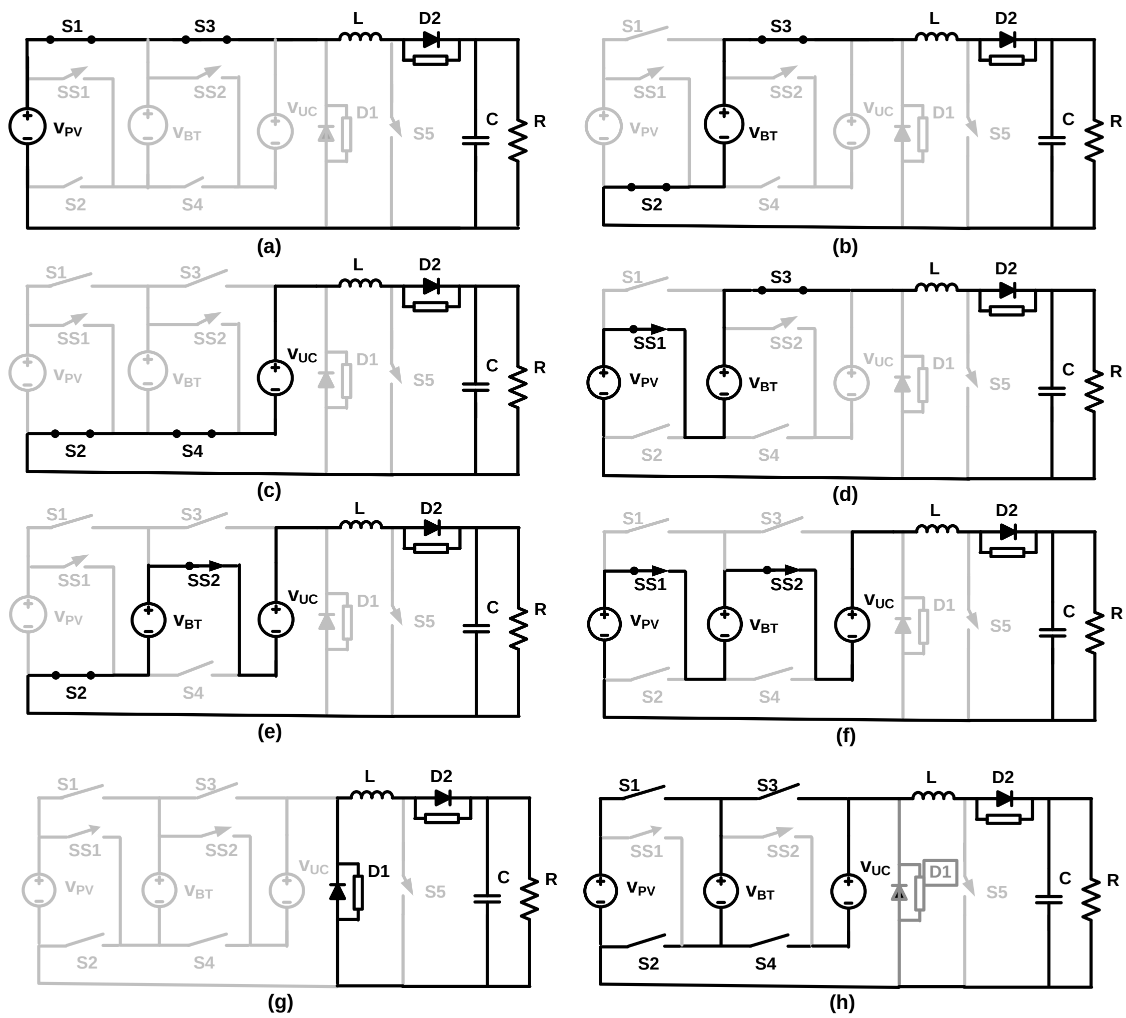

Figure2 : Working states of Multi source converter (a) VPV (b) VBT, (c) VUC (d) VPV and VBT simultaneously (e) VBT and VUC simultaneously (f) VPV, VBT and VUC simultaneously (g) Freewheeling period (h) Parallel operation of all sources

Based on switching strategy of switches S1-S4 and SS1, SS2, with diodes D1 and D2, there are seven working states extracted from the converter proposed in the work and same is presented in Fig.2 (a-h). The description of operational states is delineated as follows;

State-I: Fig. 2 (a). In this state, the driving pulse is applied to switches S1 and S3while rest of the switches are kept in the OFF state. The turning on of switch S1 connects the source VPV to the supply end of the inductor. The load is thus connected to the source VPV through inductor. As a result of switch S1 and S3 conduction, the potential at the input terminal of the inductor is at the higher potential than that at the common terminal of the load which places a reverse bias across diode D1. The inductor stores the energy in its electromagnetic field and the capacitor is charged at the same time. The load is also supplied with the power through source VPV acting alone.

State-II: Fig. 2(b). In this state, the driving pulse is applied to switches S2 and S3while rest of the switches are kept in the OFF state. The turning on of switch S2 with S3 connects the source VBT to the supply end of the inductor. The load is thus connected to the source VPV through inductor. As a result of switch S2 and S3 conduction, the potential at the input terminal of the inductor is at the higher potential than that at the common terminal of the load which places a reverse bias across diode D1. The inductor stores the energy in its electromagnetic field and the capacitor is charged at the same time. The load is also supplied with the power through source VBT acting alone.

State-III: Fig. 2(c). In this state, the driving pulse is applied to switches S2 and S4while rest of the controlled switches are kept in the OFF state. The turning on of switch S2 and S4 connects the source VUC to the supply end of the inductor. The load is thus connected to the source VUC through inductor. As a result of switch S2 and S4 conduction, the potential at the input terminal of the inductor is at the higher potential than that at the common terminal of the load which places a reverse bias across diode D1. The inductor stores the energy in its electromagnetic field and the capacitor is charged at the same time. The load is also supplied with the power through source VUC acting alone.

State-IV: Fig. 2(d). In this state, the driving pulses are applied to switches SS1 and S3 while rests of the switches are kept in the OFF state. The turning on of switch SS1 brings the source VPV in series with source VBT and combination of both the sources are connected to the supply end of the inductor. The load is thus connected to the series combination of the sources VPV and VBT through inductor. As a result of switches SS1 and S3 conduction, the potential at the input terminal of the inductor is at the higher level than that at the common terminal of the load which places a reverse bias across diode D1. The inductor stores the energy in its electromagnetic field and the capacitor is charged and at the same time the load is also supplied with the power through the combined sources VPV and VBT acting collectively in series.

State-V: Fig 2 (e). In this state, the driving pulses are applied to switches SS2 and S2 while rest of the switches are kept in the OFF state. The turning on of switch SS2 brings the source VBT in series with source VUC and combination of both the sources are connected to the supply end of the inductor. The load is thus connected to the series combination of the sources VBT and VUC through inductor. As a result of switches SS2 and S2 conduction, the potential at the input terminal of the inductor is at the higher level than that at the common terminal of the load which places a reverse bias across diode D1. The inductor stores the energy in its electromagnetic field and the capacitor is charged and at the same time the load is also supplied with the power through the combined sources VBT and VUC acting collectively in series.

State-VI: Fig. 2(f). In this state, the driving pulses are applied to switches SS1 and SS2 while rest of the switches are kept in the OFF state. The turning on of switch SS1 and SS2 brings al the three sources in series and combination of all the sources are connected to the supply end of the inductor. The load is thus connected to the series combination of the sources VPV, VBT and VUC through inductor. As a result of switches SS1 and SS2 conduction, the potential at the input terminal of the inductor is at the higher level than that at the common terminal of the load which places a reverse bias across diode D1. The inductor stores the energy in its electromagnetic field and the capacitor is charged and at the same time the load is also supplied with the power through the combined sources VPV, VBT and VUC acting collectively in series.

State-VII: Fig. 2(g). This is freewheeling state where the stored energies in the energy storing elements are being freewheeled. The inductor current finds the path through diodes D1 and D2 however the capacitor being directly connected to the load supplies its energy directly to the load. All the other switches are in the relax state and not being provided with any switching signals. This time period is also termed as TOFF period.

State- VIII: Fig. 2(h). With the aim to bring all the sources operating in parallel, the driving pulses are applied to switches S1, S2, S3, and S4 simultaneously whereas rest of the switches are kept in the OFF state. The turning on of switches brings the all the sources in parallel with one another and the combination of all the sources are connected to the supply end of the inductor. The load is thus connected to the parallel combination of the sources through inductor. As a result of switches S1, S2, S3, and S4 conduction, the potential at the input terminal of the inductor is at the higher potential than that at the common terminal of the load which places a reverse bias across diode D1. The inductor stores the energy in its electromagnetic field and the capacitor is charged at the same time the load is also supplied with the power through the combined sources acting collectively in parallel. This state is brought into action whenever there is a demand of higher current from the load under such situation the sources are brought in parallel which increases the current supplying capability of the source and as far as voltage is concerned the higher voltage amongst the three sources plays the dominant role and the state resembles the operation of either state I, state II or state III depending upon the voltage magnitude. If the magnitudes of the voltage source are taken to be same then all the voltage sources will deliver the energy together.

MIC operation is summarized in Table 1 related to the above mentioned working states of converter. The table is divided into the working state, number of conducting switches, the active source, and the voltage across inductor and the status of inductor.

Table 1: Different Working States of MIC Operation

State	Conducting Switches	Active Source	Inductor Voltage	Inductor Status
1	S_1, S_3, D_2	V_{PV}	V_{PV}-V_O	Charging
2	S_2, S_3, D_2	V_{BT}	V_{BT}-V_O	Charging
3	S_2, S_4, D_2	V_{UC}	V_{UC}-V_O	Charging
4	SS_1, S_3, D_2	V_{PV}+V_{BT}	V_{PV}+V_{BT} -V_O	Charging
5	SS_2, S_2, D_2	V_{BT} +V_{UC}	V_{BT}+V_{UC}-V_O	Charging
6	SS_1, SS_2, D_2	V_{PV}+V_{BT}+V_{UC}	V_{PV}+V_{BT}+V_{UC}-V_O	Charging
7	D_1, D_2	None	-V_O	Discharging

4. Result & Discussion:

The pulse duration or the pulse width and the repetitiveness of the pulses and their off duty are decided by the output voltage and the switching strategy adopted to meet the load voltage. Figure 2 and figure 3 shows the voltage across inductor, current through inductor and voltage across load and current through load respectively for converter operation in buck mode.

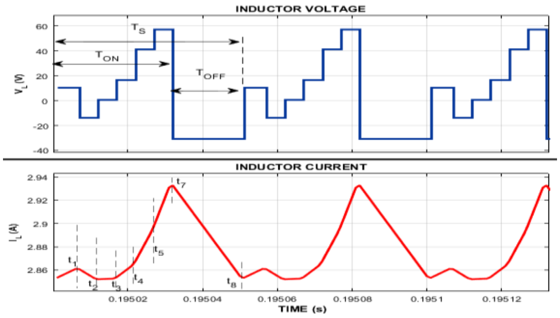

Figure2: Voltage across inductor and current through inductor for converter operation in Buck mode

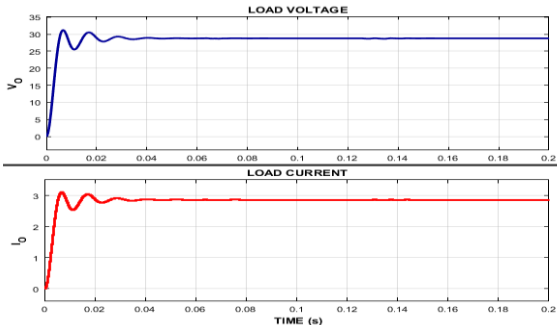

Figure 3: Voltage across load and current through load for converter operation in Buck mode

4.1 Simulation Results of Proposed MIC in Boost Mode

The duration of the pulses and the pulse frequency with their duty is decided by the output voltage and the switching strategy adopted to meet the load voltage. Figure 4 and figure 5 shows the Voltage across inductor and current through inductor and Voltage across Load and current through load respectively for converter operation in boost mode.

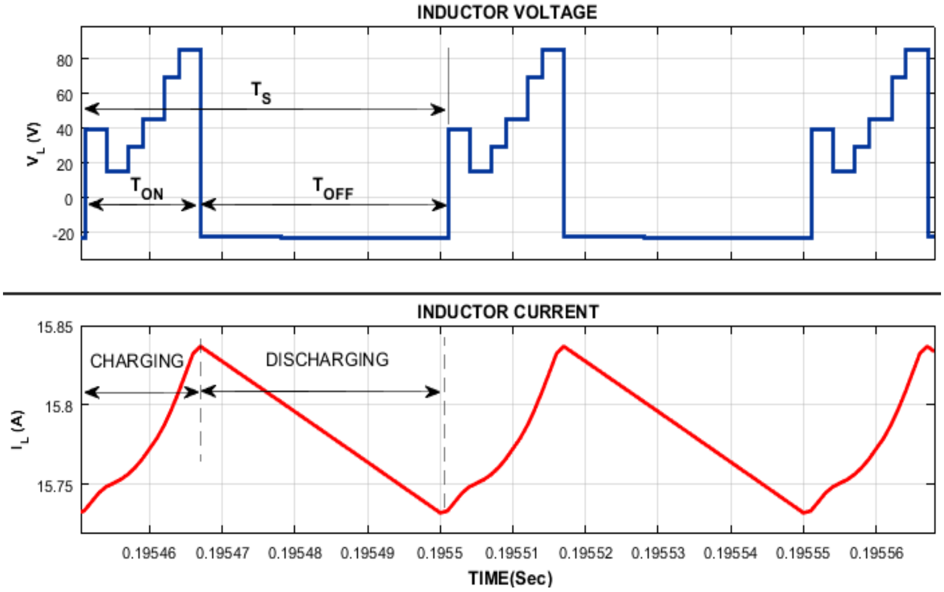

Figure 4: Voltage across Inductor and current through inductor for converter operation in boost mode

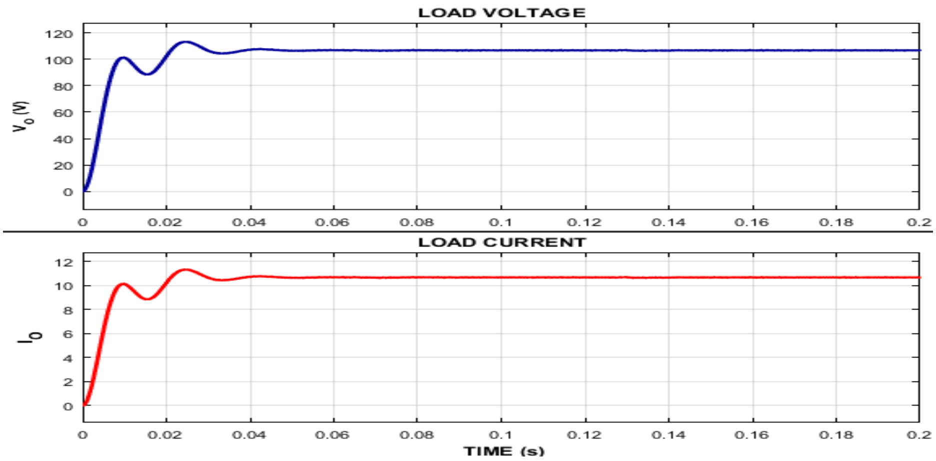

Figure 5: Voltage across load and current through load for converter operation in boost mode

4.2 Simulation Results of Proposed MIC in Buck-Boost Mode

The duration of the pulse or the pulse width and the repetitiveness of the pulses and their off duty is decided by the output voltage and the switching strategy adopted to meet the load voltage. Figure 6 and figure 7 shows Voltage across inductor and current through inductor and Voltage across Load and current through load for converter operation in buck-boost mode respectively.

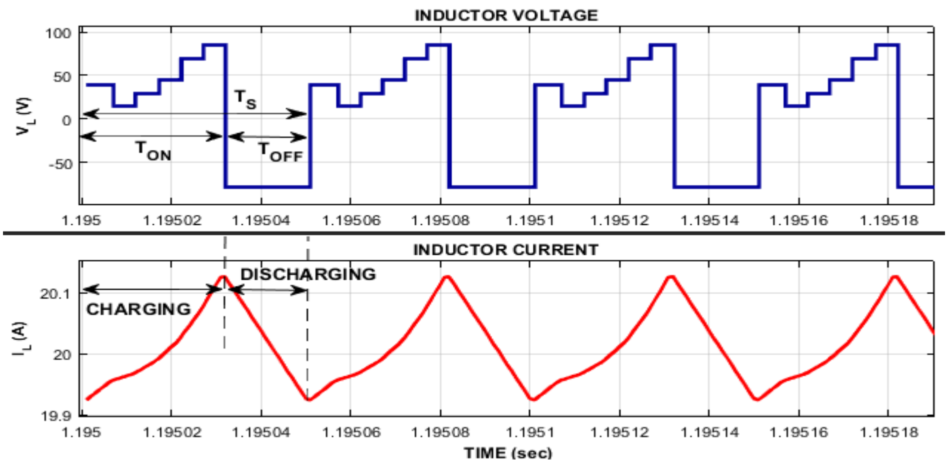

Figure 6 : Voltage across Inductor and Current through Inductor for converter operation in buck-boost mode(T_{ON}>0.5T_S)

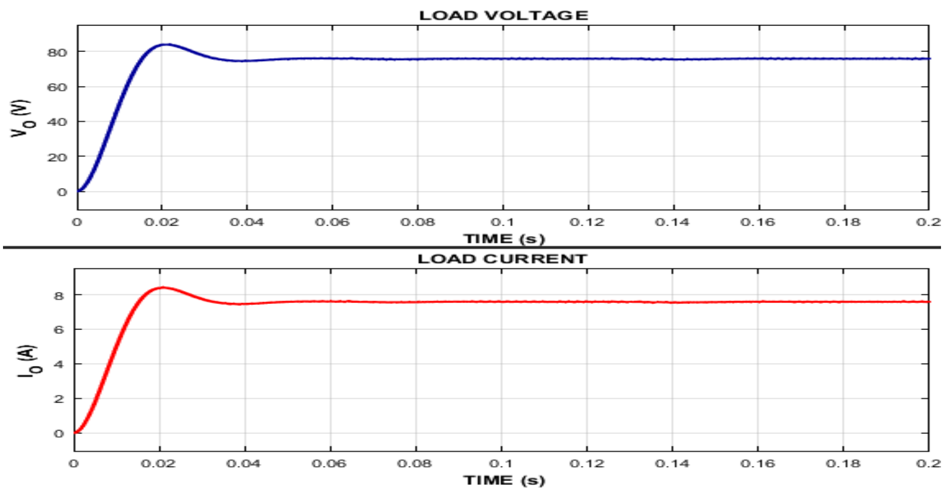

Figure 7: Voltage across Load and Current through Load for converter operation in buck-boost mode (T_{ON}>0.5T_S)

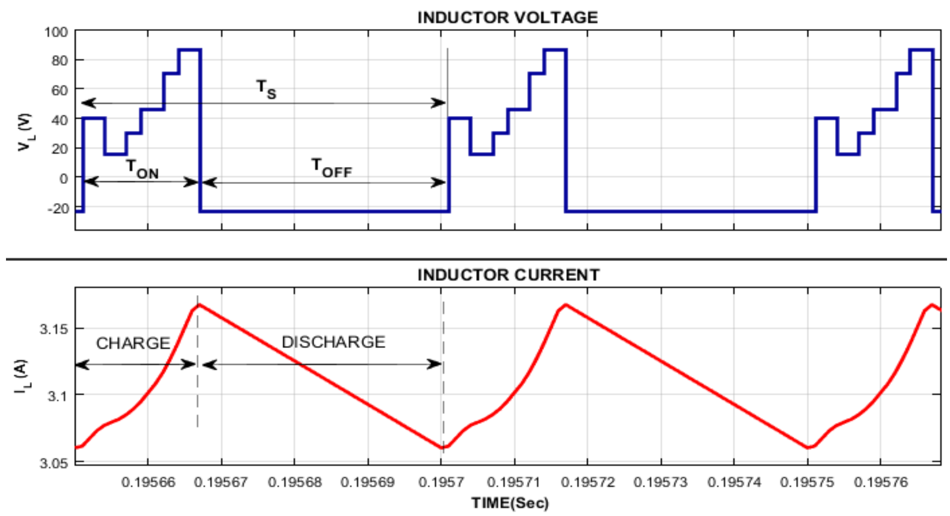

Figure 8: Voltage across Inductor and Current through Inductor for converter operation buck-boost mode (T_{ON}<0.5T_S)

The converter operation in buck-boost mode with $T_{ON}<T_S$ is presented. The duration of the pulse or the pulse width and the repetitiveness of the pulses and their off duty is decided by the output voltage and the switching strategy adopted to meet the load voltage. Figure 8 and figure 9 shows the voltage across inductor and current through inductor and the voltage across Load and current through load for converter operation in buck-boost mode respectively.

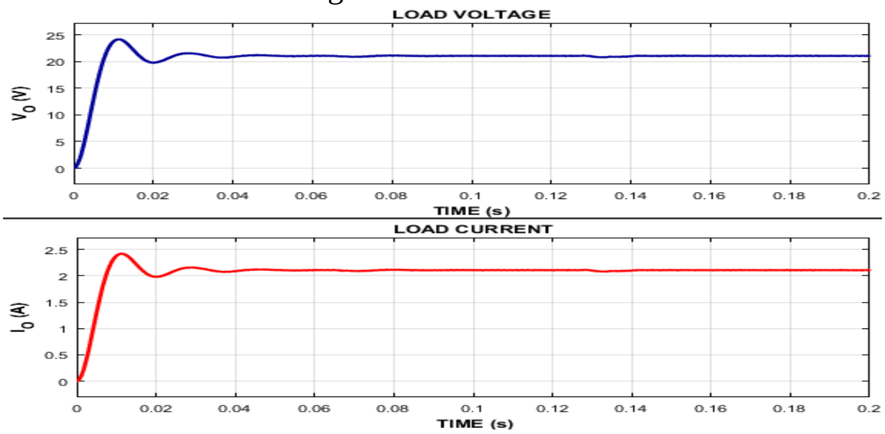

Figure 9: Voltage across Load and Current through Load for converter operation in buck-boost mode ($T_{ON}<0.5T_S$)

5. Conclusion

Multi Input Converter (MIC) and works equally well as a buck converter, as a boost converter and as a buck-boost converter along with a facility of connecting the load individually or collectively in series (or parallel) as per requirement of the load. The formulation of mathematical equations followed by theoretical analysis is done separately for both the converters with source side and load side voltages and currents under steady state, continuous conduction mode of operation. The successful operation of the presented MIC is due to the extensive simulation and mathematical study of converter functioning in as a buck converter, as boost converter and as a buck-boost converter. From the results obtained through simulation work it could be concluded that the proposed converters are proficient in not only collecting energy from the different sources with different characteristics), but it also offers higher degree of source electability, flexibility and availability. Amongst these, the other attributes of the converter include hassle free integration of the renewable energy sources and enhance the power sharing capability of the hybrid energy system.

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